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Simulation as a decision support tool for airport land use developments

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Abstract

This paper focuses on the use of discrete event simulation (DES) as a decision support tool for airport land use development. As a study case, Querétaro Airport (Mexico) is used, due to its rapid growth and the different services it offers. The SIMIO® software was used to carry out a macro-level simulation of the airport's processes, considering generic process times, flight types and demand schedules. The resulting strategic simulation model can be used to diagnose the current growth situation, analyse the airport's growth potential, and evaluate different expansion scenarios using the available land, including the expansion of the terminal building, cargo operations or MRO.

The arrival and departure of aircraft (commercial, cargo, maintenance, aviation school and private aviation) at the airport were simulated to detect bottlenecks for different expansion scenarios, that aim to find an optimal balance between the growth options in the different airport grounds. The objective is to compare the potential growth of different layout expansion possibilities.

Preliminary results indicate that land use options have a great impact on the growth potential of the airport and some general aviation activities, such as the aviation school, are interfering with the potential growth of other activities at Querétaro Airport.

Keywords: strategic simulation model; airport facilities; México City

1. Introduction

Airports must be seen as critical assets for the region, as they have been the engines for economic development through the generation of thousands of jobs. In the case of mega hubs-airport, their secondary and tertiary job impacts are numbered in the tens of thousands (ACI, 2020). Airports have diversified their sources of revenue, engaging in non-aeronautical business activities, and fulfilling an integrated hub function with landside accessibility and in a multimodality manner.

To support this, the development of *Airport Cities* has emerged since the 60s, aiming to combine aviation and non-aviation use of airport land. Airports have become dynamic centres of economic activity, incorporating several business, commercial and leisure services, both inside passenger terminals and in their surroundings, with businesses such as shopping clusters, hotels and accommodation, office complexes, conference and exhibition centres or leisure facilities, retail, and logistics centres. Therefore, this mixed-use land concept derived from the interest in developing land as an economic driver for the region needs to be further studied.

According to (ICAO, 2023), land-use planning and management is an effective means to ensure that the activities nearby airports are compatible with aviation.

Its main goal is to minimize the population affected by aircraft noise, by introducing land-use zoning around airports. Furthermore, a successfully developed airport is the product of extensive physical and environmental due diligence, regional transportation planning, a complex array of business forecasts and operational analyses, legislative empowerment, national, regional and municipal review, and enabling financing (ACI, 2020).

This paper addresses the need for a decision support tool (DST) for the development of airport land use. As a case study, Queretaro International Airport (IATA Code QRO) is used, due to the diversity of activities already existing at the airport and its surroundings. This paper contributes to presenting the baseline model of activities at Queretaro Airport to build the simulation model as a DST.

The DST should allow the comparison of different land use configuration scenarios to estimate the benefits in terms of traffic growth for commercial, cargo and general aviation. It is aimed to investigate different geographic locations for aeronautical and non-aeronautical activities where such a combination of factors can achieve maximum growth and impact on the region.

The use of discrete event simulation with the SIMIO® software is proposed to evaluate different scenarios that allow comparing how QRO airport uses its land (measured in space and capacity) to house commercial, cargo or general aviation, the latter including private jets and aviation school flights, among others.

2. Literature review

Land use distribution in airports is a crucial topic in the aviation industry, especially given the constant growth in flight demand and the need to maximize the airports' operational efficiency.

Modifications in the airports' land use are necessary to meet the increasing demand for passengers and cargo, thereby avoiding congestion and delays. Airport planners have addressed the congestion issue through airport expansions (Ryerson & Woodburn, 2014).

Airports can be roughly divided into the airside area, containing runways, taxiways, and the apron-gate complex and the landside area, including passenger and cargo terminals, space, buildings, facilities, and equipment for airport/airline-related activities, as well as the overall infrastructure of the airport ground access systems. The area of land occupied by an airport is determined by its master plan (Horonjeff & McKelvey, 1994). In addition to airport-related elements, the master plan should fit the land-use policy of the region where the airport is located, and vice versa.

Janić (2016) assesses the physical/spatial, operational, economic, social, and environmental performances of land use by airport airside and landside areas. Most airports are confronted with challenges such as incompatibility of land use and a lack of free land to expand. To adequately deal with these challenges, an effective and compatible plan of airport land use needs to be developed with components such as (i) the airport design and operational criteria, (ii) requirements for the safety of flights and unique land-use provision(s), and (iii) performance of land use.

The use of discrete event simulation (DES) and optimization tools may be an effective strategy for making informed decisions in the development of airport infrastructure projects. DES allows for modelling and analysing the complex processes that occur in airports, considering variables such as service times, passenger and aircraft flows, and facility capacity (Herrera García, 2012; Zúñiga et al., 2016; Wellens & Mújica Mota, 2017). By simulating different scenarios, it is possible to evaluate operational performance, identify bottlenecks, and propose improvements in the distribution and utilization of land use.

3. Queretaro International Airport (QRO)

Queretaro International Airport, strategically located in the centre of Mexico, has experienced significant growth in recent years, due to its crucial role in connectivity and economic development in the region (Rudo, 2021; Estrella, 2023a). Queretaro airport is located in the centre of one of the largest aeronautical clusters in the world. Nowadays made up of around 80 companies from the aerospace sector, it holds operations of leading companies in the sector such as *Bombardier Aerospace Mexico, Airbus Helicopters Mexico, Safran Landing Systems Services,* among others.

Another key feature of the aeronautical cluster of the manufacturing and suppliers' organisations, is the strong presence of Aircraft Maintenance, Repair and Overhaul (MRO) activities in the cluster, represented by TechOps, Safran, Redwings, and others. TechOps MX is the largest MRO company in Mexico and the second largest in Latin America, holding 12 maintenance lines in two hangars, and offering service to around 160 aircraft in 2018. Redwings is a fixed-base operator with MRO activities in a 4,000 m^2 area specialized in aeronautical maintenance, leader in central Mexico and with national coverage. It is the first of its kind to consolidate executive and commercial aviation maintenance.

Over the last few years, Mexico has made important investments, allowing the aerospace field to become stronger, especially in Queretaro. Since companies such as Bombardier, Aerospace Canada, Aeronnova and SAFRAN France were established, UNAQ has offered training programs mainly oriented towards aircraft manufacturing processes such as: structural assemblies, elaboration of wire harness, laminating, composite materials, machining, etc. The experience

gained due to this training program's implementation, and with a close day-to-day alliance with aeronautic companies, allows the training of aeronautical personnel with the required competencies for the process of license issuance. This represents a great opportunity for the campus to create jobs and attract global investment in aerospace and aeronautic technology in Mexico (UNAQ, 2023).

The *cargo* sector has also been growing in the last years, moving in the year 2009 about 1844 tons of cargo to move more than 72,000 tons by 2022 (SCT, 2023). Queretaro International Airport ranked as the third terminal in the country with the highest cargo flow after Mexico City and Guadalajara airports. Nowadays, it counts with air cargo companies like TSM, FedEx, DHL, Atlas, Panalpina and Magma. DHL is building a hub for their operations as the biggest in Latin America, processing 41,00 items per hour in a 30,000 m^2 hangar, and using innovative technology.

Queretaro Airport also offers *commercial flights* to domestic destinations such as Cancun, Monterrey, Guadalajara, Tijuana, Mexico City, Puerto Vallarta, among others. It also serves international flights to destinations in the United States such as Dallas, Houston, and Chicago, reporting around 1.2 million O&D passengers in 2022, with a network of 26 non-stop destinations.

Compatible land-use planning and management is also a vital instrument to ensure that the gains achieved by the diverse set of activities can grow harmonically and successfully. It is important to understand in depth the future opportunities and limitations of route development, to align these with the needs of the future tenants, i.e., the companies that intend to locate in the airport city.

Hence, the airport should explore alternative uses for some of these, generally small parcels, of land that can generate additional levels of revenue and higher levels of service for their constituents if properly planned. Without a doubt, thorough strategic planning is utterly important. This posed challenges in terms of efficiently distributing its facilities to serve different types of activity, including commercial, cargo, general aviation (FBOs, flight schools and charter or other flights) and MRO facilities.

4. Methodology

This section describes the methodology implemented in this paper, including the simulation approach and the corresponding determination of input data. The simulation will be conducted using discrete event systems (DES), which is a modelling approach where the state of system variables changes only at discrete points in time; the term "event" is used to represent the occurrence of discontinuous changes at possibly unknown intervals (Flores de la Mota et al., 2017).

Figure 1 shows the methodology that was implemented to carry out the simulation.

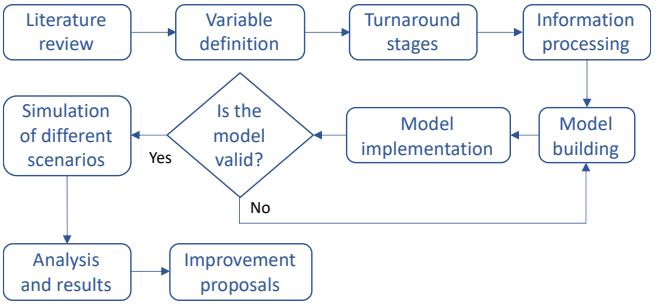

Figure 1. Study methodology.

The study objective was to simulate the effect of modifications in the QRO airport layout, depending on the benefits offered by different types of flights (cargo, aviation school, commercial, general aviation) to the development of the Queretaro region. Included research steps were (AERTEC, 2023):

I. Literature review on DES for strategic modelling, documental research on QRO airport, and information analysis on corresponding operations from January to May 2023.

II. Identification of the required variables to be included the simulation model, such as the current distribution by operation type at QRO airport, processing times at the facilities, time intervals between operations, and available square meters of space on the platforms for different types of flights.

III. Definition of the different stages of the landing and turnaround process at QRO airport in the simulation model: aircraft landing - runway entrance –taxiway entrance - apron entrance – gates - departure control – apron exit - taxiway exit - runway exit - aircraft takeoff (cfr. Figure 2).

IV. Building of the simulation model in the Simio® software.

V. Model validation: once the model has been designed, its accuracy and ability to accurately represent the airport system of QRO Airport must be validated. This involves comparing simulation results with real data or expert knowledge to ensure that the model produces reliable and representative results.

VI. Simulation runs: in this step, the simulation is executed for the defined scenarios, using the developed model. Parameters such as interarrival rate, distribution by type of operation, and processing times are set. The simulation is conducted for a specific time, and relevant results are registered.

VII. Analysis of the results to identify areas for improvement in the layout and optimization opportunities.

VIII. Based on the results analysis, specific improvements in the layout at QRO airport can be proposed to promote the development of the Queretaro region.

4.1. Estimated demand

According to data provided by (SCT, 2023) passenger demand has been increasing in recent years. In 2019, 1,957,354 passengers were recorded, representing an 8.4% increase compared to the previous year. In 2020, the COVID-19 pandemic heavily impacted the aviation industry, and the number of passengers decreased significantly worldwide, including at QRO Airport. However, according to the most recent data, in January 2022 there was a 22.7% increase compared to the same month of the previous year, indicating a possible recovery in passenger demand.

4.2. Simulation

Figure 2 shows the simulation logic for the aircraft ground process at macro level. The process from aircraft landing to takeoff is considered in the model, dividing the process according to the physical space or facility where each step takes place. The arrival and departure processes at the airport were analysed based on the classification of flight types (commercial, cargo, general aviation, aviation school). The objective was to identify bottlenecks that may arise during operations.

The aim of the simulation is to improve the land use within the airport's facilities, according to the contribution of each type of flight. The goal is to resize the operations to achieve a maximum growth and development for the airport and, consequently, for the region.

4.3. Simulation parameters

To carry out the simulation, the current land use distribution at QRO Airport was added to the model. Table 1 shows this distribution by flight type, according to the classification data provided by QRO airport's master plan (AIQ, 2009).

Table 1. Current distribution of land use at QRO airport

Flight type	Platform surface (m²)	percentage of total land use
Cargo	35 000	20%
Commercial	125 000	72%
General	14 4000	8%
Total	174 400	100%

Simulation parameters include:

- *Interarrival rate*: according to data provided by the operational performance results of Queretaro Airport (January-May 2023) (ASA, 2023), the average number of daily operations at QRO Airport indicates that aircraft of any flight type arrive every 15 minutes during a high-flow schedule. The arrival distribution was considered to be exponential.

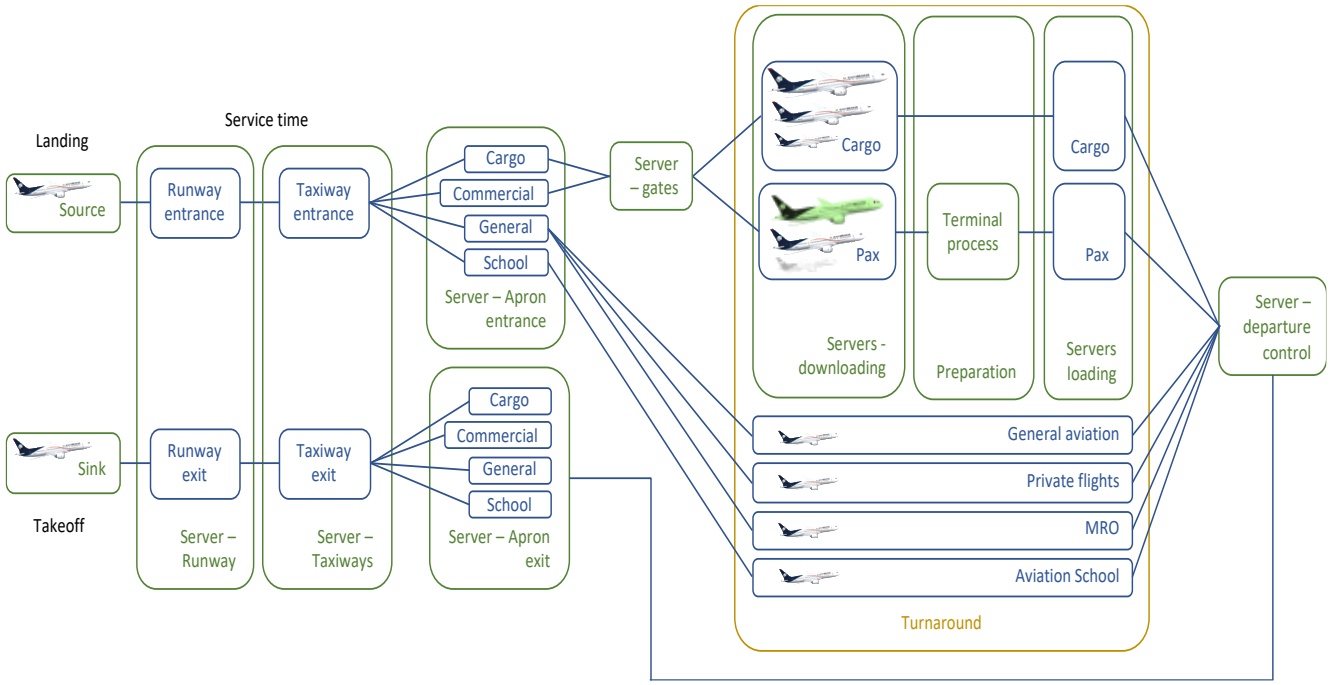

Figure 2. Representation of the implemented simulation logic.

- *Arrival distribution per flight type*: the percentage of arrivals for each type of flight is determined in the simulation model by the distribution of operations at QRO airport, as shown in table 2, according to the data provided by Operational performance results of Queretaro Airport (January-May 2023; ASA, 2023).
- *Server operation times (Server OT)*: the servers in the simulation represent the time that the aircraft spends using the runway, taxiway, apron, and gates. Four types of flight are considered: cargo, commercial, general, and aviation school. No information was available for the server operation times; however, they depend on the aircraft size. Server operation times were modelled with a triangular distribution. For general aviation and aviation school flights, where smaller aircraft are used, the triangular function (1, 2, 3) was implemented. For cargo and commercial flights, a triangular function (2, 4, 6) was used.
- *Path operations times (Path OT)*: as for the times an entity spends on either of the timepaths, they also depend on the size and classification of the aircraft. Similarly, a triangular function (1, 2, 3) was used for general aviation flights, whila for cargo and commercial flights, a triangular function (2, 4, 6) was used.
- *Simulation run length*: the simulation was carried out for a 4-week scheme.

Table 2. Table of Simio input data

Aircraft arrival	Arrival %	Server OT	Path OT
Cargo	19	Random.Triangular (2, 4, 6)	Random.Triangular (2, 4, 6)
Aviation School	25	Random.Triangular (1, 2, 3)	Random.Triangular (1, 2, 3)
General	20	Random.Triangular (1, 2, 3)	Random.Triangular (1, 2, 3)
Commercial	36	Random.Triangular (2, 4, 6)	Random.Triangular (2, 4, 6)

The data from table 2 was entered into the Simio software, considering the current distribution of operations by flight type at QRO Airport. Additionally, their operation times on servers and paths were input based on their respective classifications.

4.4. Operations distribution at QRO airport

In the latest data obtained by the Operational performance results of Queretaro Airport (January-May 2023; ASA, 2023), the recorded operations at QRO Airport are as follows:

There have been 21 125 operations at the airport in the analysed period, with an average count of 4 225 monthly operations. This represents a 1.8% increase compared to the same period in 2022. Accordingly, the simulation model's estimate are 140 operations in a normal day at the airport, with a 24 hours operation daily and a 7 days-a-week service.

Out of the 21 125 operations at QRO Airport this year, 45% were general aviation operations; of these, more than 50% are generated by the aviation school, accounting for 24.7% of the total operations at the airport. A total of 36% were commercial operations, and 19% are cargo operations.

Comparing the months of January to May 2023 with the same period in 2022, there has been a 48.7% increase in commercial operation, with a total of 621 808 passengers. Of these, 74% are from domestic flights (461 350 passengers) and 26% are from international flights (160 458 passengers).

In the analysed period, 32 636 tons of cargo was moved, with an average monthly volume of 6 527 tons, representing an 8.4% increase compared to the previous year for the same period. 59% was international cargo (19 388 tons), whereas 41% was domestic cargo (13 247 tons). For domestic cargo, 35% corresponded to arrivals (6 810 tons) and 65% to departures (12 579 tons). For international cargo, these percentages change to respectively 32% for arrivals (4 262 tons) and 68% for departures (8 985 tons).

4.5. Scenarios

The simulation was conducted for three different scenarios, modifying the distribution of operations to propose changes in the land use, aiming at maximum the benefits at the QRO airport.

The first scenario considers the current operating conditions of the airport, with the observed distribution by type of operation: cargo 19%, aviation school 25%, general aviation 20% and commercial flights 36%.

The second scenario projects a 25% increase in cargo operations in response to the airport airport's dynamic cargo transportation. This resulted in a readjustment in the distribution by type of operation (Estrella, 2023b). According to this projection, a readjustment in the airport land use would be necessary, proposing an expansion in the layout.

The third scenario involves planning a modification that increases cargo and commercial operations. This includes increasing cargo operations by 15% and commercial operations by 10% due to the increased demand for these types of flights. Modifications to the layout would also be required to meet the increased demand for these types of flights.

4.6. Contribution of airport operation types

The importance of each kind of operation was considered in the simulation model, based on factors such as job creation, economic contribution to the

region, societal benefits, national and international trade, regional and global connectivity, commercial relationships, tourism, profitability, demand, and growth potential for each type of flight at Queretaro International Airport. Table 3 shows the relative importance, expressed in a Likert scale.

In table 3, the ranking by importance of each type of flight was carried out by comparing the number of named factors in the previous paragraph that are attended by each type of flight.

- 5: the flight type meets between 9 and 10 factors
- 4: the flight type meets between 7 and 8 factors.
- 3: the flight type meets between 4 and 6 factors.
- 2: the flight type meets between 2 and 3 factors.

Table 3. Relative importance of different types of flights

Flight type	Level of importance
Cargo	5
Commercial	4
General	3
Aviation School	2

The number 5 represents the highest level of importance in this context. The used scale is qualitative and can be easily adapted in the simulation model.

5. Results

The results and benefits obtained regarding the airport's performance are presented for the three simulated scenarios.

As a result of the simulation in the first scenario, where QRO airport operates under the current conditions, the aviation school was identified to occupy a significantly high number of operations (724), accounting for 24.7% of the total.

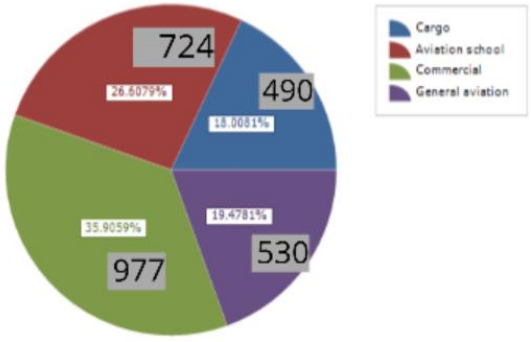

Figure 3. Distribution by operation type; scenario 1.

The simulation results for the second scenario, corresponding to a 25% increase in cargo operations, indicate that it would require an expansion of the cargo layout by 25% as well. This means increasing the cargo platform area by 8 750 m², resulting in a total space of 43 750 m².

Table 4 shows the simulation results with the readjustment in space and operations at QRO airport for the second scenario proposal.

Table 4. Results of scenario 2, with its space and operations readjustment

Flight type	Platform surface (m²)	Number of operations
Cargo	43 750	613
commercial	125 000	977
General, aviation school	14 400	1254
Total	183 150	2 854

In the results of the third scenario, proposing a 15% increase in cargo flight operations and a 10% increase in commercial flight operations, modifications to the layout were also required to accommodate these operations. The cargo platform would need to increase by 15%, which amounts to 5 250 m², resulting in a total area of 40 250 m². As for the space allocated to commercial flights, it would be necessary to increase it by 10% with respect to its current capacity, which would require an extension of 12 500 m², resulting in a total space of 137 500 m².

Table 5 shows the simulation results with the readjustment in space and operations at QRO airport for the proposal of the third scenario.

Table 5. Results of scenario 3, with its space and operations readjustment

Flight type	Platform surface (m²)	Number of operations
Cargo	40 250	564
commercial	137 500	1075
General, aviation school	14 400	1254
Total	192 500	2 893

QRO Airport is strategically located in the centre of Mexico, providing logistical possibilities at both the national and international levels. This has attracted investments from important companies such as DHL, which plans to invest $120 million to expand and automate its hub at the airport. This investment will not only improve logistical capacity but also generate 200 new jobs and promote sustainable technology to reduce carbon emissions.

Considering these investments, the airport's growth potential, and the results of the simulation, it is

recommended to expand the airport land. The simulation model is an interesting tool to compare different expansion options, subject to the available space.

6. Conclusions

Based on the simulation results, we conclude that if it is not possible to expand the airport layout and it is necessary to operate under the current space conditions, it is recommended to decrease the operations of the aviation school since this type of flight currently accounts for a very high percentage of operations and does not provide much benefit to the region, as can be observed in Table 2.

The projection and increasing demand currently being observed for commercial and cargo flights suggest that more space would be needed to allocate these types of flights to operate optimally. To meet the foreseen demand in the future, the facilities' layout extension for cargo and commercial flights at QRO airport should be expanded. This will allow for the harnessing of growth and economic benefits associated with these flight classifications, providing a greater boost to the airport and the region as a whole. The investment from companies like DHL demonstrates the growth and development potential that can be achieved by expanding the airport's facilities.

There are proposals for expanding operations in MRO flights, and this is beneficial as it would generate employment opportunities.

Given the current land use conditions in the layout, the lack of space around the airport could be a limiting factor in obtaining maximum benefit, as it could hinder the development and growth of QRO airport and, consequently, the region's growth.

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